Direct coupling of POF to VCSEL with patterned polymer guiding hole

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Introduction

Optical interconnections and fiber-optic data links are expected to overcome the bottlenecks of the metal wiring systems, such as propagation delay and electro-magnetic interference (EMI). Vertical-cavity surface-emitting lasers (VCSELs) show great promise for the light source because of their two-dimensional (2-D) array configuration, low-dissipation power and low-cost production. Since the optical fiber coupling to VCSEL is a key technology for reducing costs of the assembly, passive alignment schemes without additional optics have been studied. Alignment-parts based coupling methods were demonstrated using the micro-optical bench (MOB) [1] and PMMA spacers with guiding holes [2]. On the other hand, direct coupling of VCSEL was achieved using fiber guiding holes fabricated by etching the GaAs substrate [3].

In this study, we report a novel coupling method using polymer guiding holes patterned on the top of VCSELs. The polymer holes are fabricated by a standard photolithography, and the optical fibers are directly inserted into the guiding holes. This simple procedure can realize the low-cost assembly, since no etching processes or alignment parts are required.

Design and Fabrication

We used the SU-8 that is a near-UV photoresist made by MicroChem Corp. as a polymer material of the guiding holes, because of its thickness over 100 μm and vertical edge profiles. High transparency of this material is also preferable for alignment and insertion process of the optical fibers. Compared to the silica fibers, POFs are suitable for short-distance and low-cost interconnection modules due to their high flexibility and their facility of optical coupling. Recently, perfluorinated polymer based graded-index (GI) POF was developed for realizing high bit-rate optical transmission at near infrared region [4]. We applied such GI-POF with 124-μm core-diameter, 500-μm outer-diameter, and a numerical aperture of NA = 0.18.

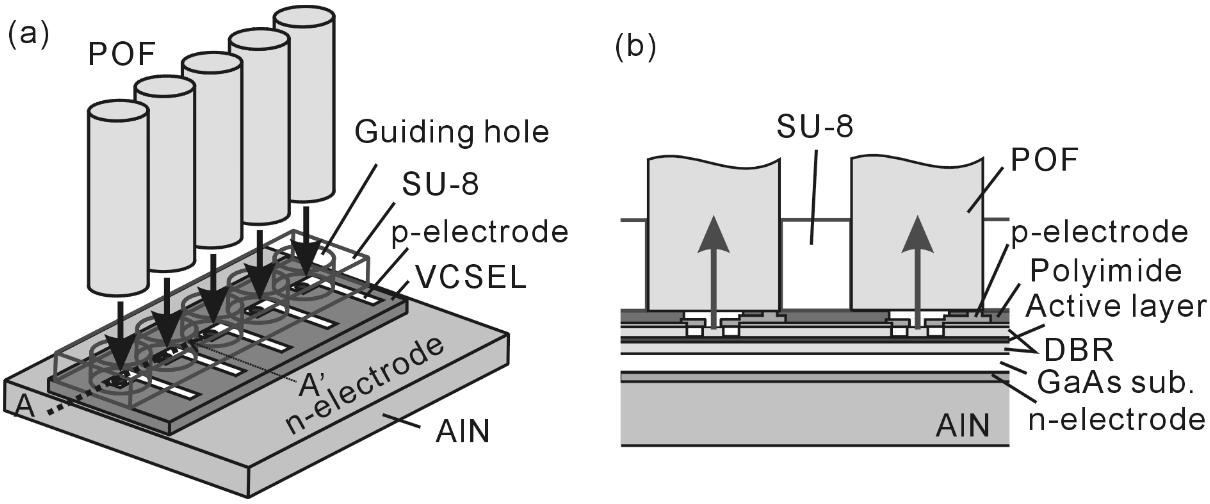

Fig.1 Schematic design of the VCSEL to POF direct coupling.

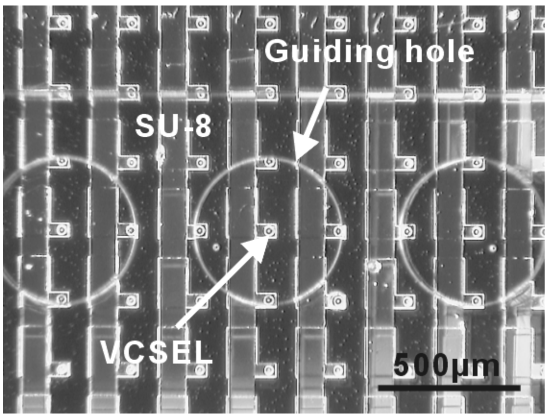

Fig.2 Micrograph of the top view of the patterned polymer guiding holes.

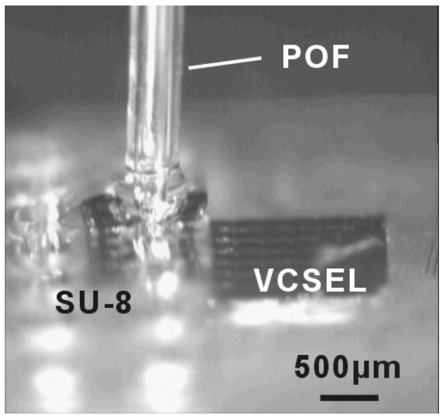

Fig.3 Side-view image of the POF inserted into the guiding hole on the VCSEL.

The VCSEL-to-POF coupling schemes are shown in Figs. 1 (a) and (b). Figure 1 (b) shows the cross sectional view of A-A' in Fig. 1 (a) after inserting the POFs. An 830-nm top-emitting VCSEL array was bonded on an AlN submount. The n-side and p-side DBR layers consisted of 30.5 periods and 22 periods of $Al_{0.12}Ga_{0.88}As$/AlAs, respectively. The active region was inserted at the center of a one-lambda cavity, and was composed of three 6nm GaAs quantum wells separated by 8nm $Al_{0.3}Ga_{0.7}As$ barriers. In the p-side layer, an air-post of 15-μm diameter was formed and buried by a polyimide.

For electrical wiring on the surface, the VCSELs were covered with a 2-μm thick polyimide that had light output windows and contact holes. The polyimide layer also carried out the functions of a spacer and a stopper of the inserting fibers. On the polyimide layer, a p-electrode wiring and the guiding holes were fabricated. The SU-8 film was patterned and polymerized to form the holes of 510 μm in diameter, 750 μm in period, and 200 μm in thickness by the UV-lithography and the post-bake at 100 °C. These processes could be carried out in a sequence of VCSEL fabrication. Figure 2 shows a micrograph of the top view of the patterned polymer guiding holes on the VCSELs. Although many VCSELs were fabricated in the arrayed formation, we operated the VCSELs in the center of the guiding holes. A center deviation less than 5 μm was achieved without mechanical means such as guide pins.

The POFs were prepared with a 0.5 m length (attenuation = 0.05 dB) using a knife and the end facets were polished. The POF coupling was performed by inserting into the guiding holes using a micrometer stage, and then the POFs were fixed in their positions by a transparent epoxy glue. A side-view image of the assembly after inserting one fiber is shown in Fig. 3. The POFs were fixed one by one at this time. By using fiber ribbons, large-scale interconnect modules including 2-D arrays will be possible by the simple method.

Optical Characteristics

Measured typical light-current (L-I) characteristics of the VCSEL output and the POF output after coupling are shown in Fig. 4. The coupling efficiency plotted in Fig. 4 was defined as the ratio of the POF output to the VCSEL output, here. The measurement was carried out under continuous wave condition at 23 °C. Previously, we confirmed that the polymer process did not change the VCSEL characteristics at all. The coupling efficiency depended on the drive current of the device: a maximum efficiency of about 80% was measured just above a threshold current I_{th} (= 3.3 mA), while the efficiency decreased to a level around 50% for higher currents. A deviation of the efficiency at a drive current of 10 mA (= 3.0 I_{th}) was less than 5 % in adjoining three devices.

The emission far-field patterns (FFPs) of the VCSEL change as a function of the current, as shown in the inset of Fig. 4. Although a narrow and symmetric pattern was obtained around the threshold current, FFPs got wide and asymmetric as the current’s increasing. As a result, less

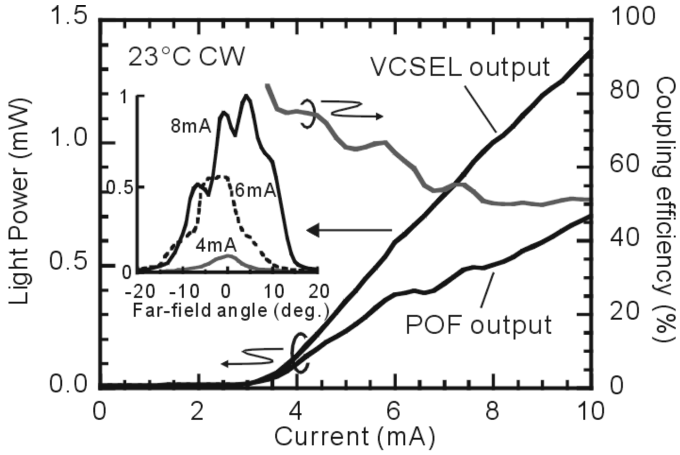

Fig. 4 L-I characteristics and coupling efficiency. The inset shows far-field patterns of VCSEL.

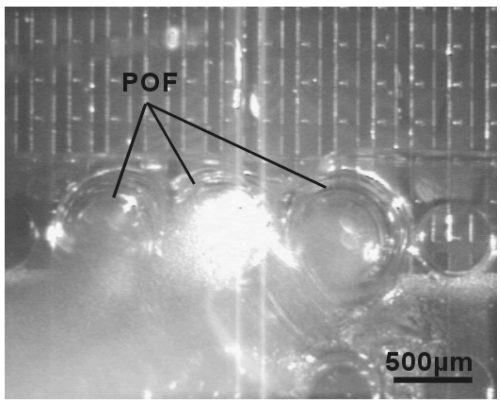

Fig. 5 Top view image of direct-coupled VCSEL to POF, where the center device is lasing.

power was captured in the NA of the POF for higher currents. The asymmetric patterns come from multimode emission and non-uniform carrier distribution due to the wide air-post VCSELs. The butt-coupling efficiencies into fibers of higher order transverse mode decrease considerably, showing the dependence upon driving currents [5]. Figure 5 shows a top view image of direct coupled VCSEL to POF, where the injection current of the center device is 6 mA. Light emission is observed through the fiber, indicating the light power leakage out of a core of the POF. Since the alignment deviation of our strategy was small, a combination of VCSELs with narrow beam divergence and high-NA fibers will realize high direct coupling efficiency.

Conclusion

We have demonstrated the simple and accurate passive alignment method of POF to VCSEL for direct butt coupling. Fiber guiding holes were fabricated on the top of the VCSELs directly by a standard photolithography using the thick near-UV photoresist. The center deviation of the holes under 5 μm and the coupling efficiency between 80 % and 50 %, which depended on driving currents, were obtained. Further improvement in the coupling efficiency will be expected by using VCSELs with narrow beam divergence and high-NA POFs. This novel coupling assembly is very attractive for realizing high-performance, low-cost optical links and interconnections.

Acknowledgment

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